The Coolangatta Latite Member and Associated Tuffs: Newly Identified Basal Units in the Gerringong Volcanics, Southern Sydney Basin, NSW

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Three newly identified stratigraphic units are described from the Broughton Formation in the southern Sydney Basin. They include the Back Forest Tuff Bed, which occurs near the base of the Westley Park Sandstone Member, the Koo-Lee Tuff Member, a laterally extensive pyroclastic ash bed in the middle of the sandstone member, and the Coolangatta Latite Member, a lava flow at the top of the sandstone member. These units form part of the Gerringong Volcanics and precede the previously identified lowest latite member, the Blow Hole Latite Member. The tuff beds consist of shallow marine, pyroclastic deposits, one of which is slightly fossiliferous. The Coolangatta Latite Member consists of a major lava flow at the top of, and a few lava-like lenses interstratified with, the Westley Park Sandstone Member. Evidence indicates a relatively proximal source from volcanoes ranging from mild Strombolian to violently explosive Vulcanian, Plinean and/or Surtseyan phreatomagmatic eruptions. The described deposits represent small or distant components of a much larger volcaniclastic apron surrounding a series of vents which were probably located to the southeast of Mount Coolangatta.

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KEYWORDS: Late Permian, Mount Coolangatta, latite, tuff beds, Gerringong Volcanics, Broughton Formation, Sydney Basin, marine, volcaniclastic, volcanism

INTRODUCTION

Mount Coolangatta, a prominent hill east of Nowra on the south coast of New South Wales (Fig. 1), is composed of early Late Permian (Kungarian-Kazanian) marine and volcanic rocks. These belong to the Berry and Broughton Formations of the Shoalhaven Group in the southeastern Sydney Basin (Table 1).

This study provides a detailed stratigraphy of Mount Coolangatta, the only moderately exposed complete outcrop of the Westley Park Sandstone Member in the lower Broughton Formation. Stratigraphic mapping was achieved using an altimeter and 1:25,000 and 1:100,000 scale topographic maps (Sheet 9028). Particular attention was paid to volcanic features, such as lava flows, tuff deposits, and coarse volcaniclastic sandstone and clasts within the sedimentary succession. Fossils were observed and/or collected and identified at all available sites for use in palaeoenvironmental reconstruction.

Problems encountered in the field included the heavily eroded and weathered nature of many outcrops, the steep heavily vegetated gullies and the pervasive bioturbation that commonly obliterates any trace of primary sedimentary structures in the sedimentary succession.

This paper defines three new stratigraphic units, which have been named in accordance with current lithostratigraphic nomenclature in Australia (Staines 1985). The new names have been registered with the AGSO Australian Stratigraphic Names Database, Canberra, ACT.

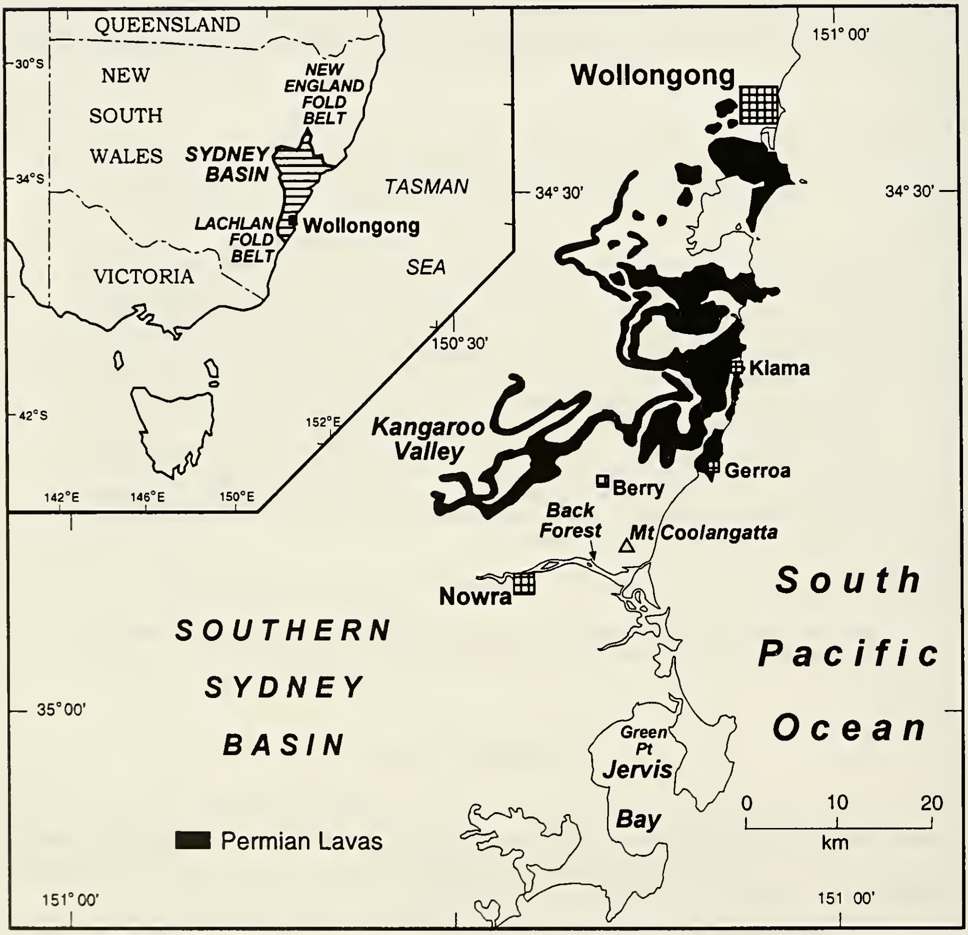

Figure 1. Location map of the Mount Coolangatta area showing the extent of Late Permian shoshonitic lavas (after Carr 1983).

Table 1 Permian stratigraphic units in the southern Sydney Basin, showing subdivisions of the Shoalhaven Group (modified after Carr, 1983)

<table>
<tr><td rowspan="14">LATE PERMIAN</td><td colspan="3">ILLAWARRA COAL MEASURES</td></tr>
<tr><td rowspan="16">SHOALHAVEN GROUP</td><td rowspan="11">Broughton Formation</td><td>Cambewarra Latite Member</td></tr>
<tr><td>Dapto Latite Member</td></tr>
<tr><td>Saddleback latite Member</td></tr>
<tr><td>Jamberoo Sandstone Member</td></tr>
<tr><td>Bumbo Latite Member</td></tr>
<tr><td>Kiama Sandstone Member</td></tr>
<tr><td>Blow Hole Latite Member</td></tr>
<tr><td>Coolangatta Latite Member</td></tr>
<tr><td>Koo-Lee Tuff Member</td></tr>
<tr><td>Back Forest Tuff Bed</td></tr>
<tr><td>Westley Park Sandstone Member</td></tr>
<tr><td colspan="2">Berry Formation</td></tr>
<tr><td colspan="2">Nowra Sandstone</td></tr>
<tr><td rowspan="4">EARLY PERMIAN</td><td colspan="2">Wandrawandian Siltstone</td></tr>
<tr><td colspan="2">Snapper Point Formation</td></tr>
<tr><td colspan="2">Pebbley Beach Formation</td></tr>
<tr><td colspan="3">TALATERANG GROUP</td></tr>
</table>

Geological Setting

The Sydney Basin (Fig. 1) is bounded to the east by the Palaeozoic southern New England Fold Belt and its southern extension, the Currarong Orogen (Jones et al. 1984) or Northumberland Ridge (Brakel 1984). To the west it non-conformably and unconformably overlies Early to Middle Palaeozoic magmatic and meta-sedimentary rocks of the Lachlan Fold Belt. The eastern orogen acted not only as a provenance for epiclastic material, but also as a centre for latite extrusions (Harper 1915; Raam 1964, 1969; Mayne et al. 1974; Jones et al. 1984; Shaw et al. 1991; Evans and Migliucci 1991; Veevers et al. 1994a).

The Permian Shoalhaven Group (Table 1) forms the main sedimentary fill in the southern Sydney Basin. It consists predominantly of an alternating sandstone and siltstone succession deposited on an extensive open continental shelf subjected to glacio-eustatic sea level changes and variable rates of subsidence (Gostin and Herbert 1973; Herbert 1980, 1995; Jones et al. 1986; Tye et al. 1996; Bann 1998; Eyles and Eyles 1998). Development of a Late Permian volcanic island chain to the east of the present coastline brought about a drastic change in sediment provenance from western quartz-rich craton-derived sediment to volcaniclastic orogen-derived sediment from the east. The first documented sign of this emergent volcanic chain is a tuff emplaced in the upper Wandrawandian Siltstone at Green Point, northeast Jervis Bay (Runnegar 1980b; Shaw et al. 1991; Veevers et al. 1994a). However, Tye et al. (1996) suggested the orogen to the east may have initially emerged at the end of Snapper Point Formation deposition when the palaeo-environment changed from storm-dominated to longshore current-dominated.

By the Late Permian, volcanic extrusive and associated volcaniclastic deposits swamped the southeastern Sydney Basin, with lava flows and intrusions typical of the shoshonitic rock association (Joplin 1968; Carr 1985, 1998). Volcaniclastic detritus is a major component in both the Berry Formation and overlying Broughton Formation that are present in the Mount Coolangatta area and represent the last phases of deposition of the predominantly marine Shoalhaven Group.

The predominantly dark grey fine-grained Berry Formation overlies the Nowra Sandstone gradationally and represents a continuation of the upper Nowra transgression (Le Roux and Jones 1994). It was deposited in a shallow marine environment between the craton in the west and an emerging orogen to the east. Anoxic conditions in and above the substrate are indicated by the sparse fossiliferous layers and low species diversity (Runnegar 1980a; Jones et al. 1986). Increasing volcanic activity in the eastern orogen produced a succession of volcanic-derived sandstones, known as the Broughton Formation, interspersed with latite flows of the shoshonitic Gerringong Volcanics (Harper 1915; Raam 1964; Carr 1983, 1984, 1985). These units represent a regressive phase following the deposition of the Berry Formation.

Gerringong Volcanics

Carr (1983, 1984) remapped and clarified the stratigraphic nomenclature of the Broughton Formation and Gerringong Volcanics, including a bibliography on the history of the naming of the stratigraphic units. He suggested, based on geochemical evidence, that the Blow Hole Latite Member, the first flow of nine recognised within the Gerringong Volcanic Facies, cropped out on Mount Coolangatta, rather than the Bumbo Latite as previously suggested by Harper (1915).

Facer and Carr (1979) and Carr and Facer (1980) assigned K-Ar minimum ages of 253-238 Ma to the Gerringong Volcanics. Roberts et al. (1994), using zircon SHRIMP dates from Queensland and the Newcastle Coal Measures, and correlations based on brachiopod zones, suggested that the Gerringong volcanism is older than 253 Ma. Veevers et al. (1994) suggested a stratigraphic age of 260 Ma and, more recently, Veevers (2000) suggested 265 Ma for the tuff in the Wandrawandian Siltstone based on fossil evidence. Dating of the pyroclastic tuff beds described here from Mount Coolangatta could supply new insights into the timing and onset of volcanism within the southern Sydney Basin.

SEDIMENTARY AND PYROCLASTIC FACIES IN THE BERRY AND BROUGHTON FORMATIONS

Facies 1

Description: Laminated or massive, bioturbated, light to dark grey, muddy, fine- to medium-grained siltstone. A few areas show preservation of upper plane laminated and pelagic divisions of turbidite beds but most bed boundaries are difficult to discern due to pervasive bioturbation throughout the exposure. The trace fossil assemblage is characteristic of the Cruziana ichnofacies, although it is commonly overprinted by deep tiered *Zoophycos* burrows. Some micro-cross-bedding is preserved. Pyrite is commonly present in the dark fine-grained siltstone. Fossils and clasts and are either locally common, rare or absent. Large dropstones are absent. Spheroidally (onion-skin) weathered outcrops are a feature.

Interpretation: The pervasive overprinting of the Cruziana-type assemblage in Facies 1 suggests slow rates of deposition of suspended fines in a low-energy marine environment around or just below storm wave-base. Most of the succession consists of material settled from suspension but a few micro-cross-beds reflect occasional weak bottom currents in a protected shallow marine environment. This facies represents the lowest depositional energy rates and the highest degree of reduction (anoxia) in the study area which may indicate that it was deposited during maximum relative sea level depths. This facies is only found in the Berry Formation.

Facies 2

Description: This facies consists of massive fine- to medium-grained sandstone units. Bed thickness ranges from 0.20 m to >10 m, the average being approximately 0.8 m. No relationship between bed thickness and grain size was found. Trace fossils (Cruizana ichnofacies with *Zoophycos* assemblages), body fossils and clasts are often abundant, as is spheroidal (onion-skin) weathering. Pseudo-cross-lamination (cross-bedding) was sporadically discernible.

Interpretation: This facies reflects deposition in an upper offshore environment between storm and fairweather wave-base. The massive nature of the unit reflects complete biogenic homogenisation or, alternatively, rapid deposition from mass-flows. Sediment transport probably occurred either via storm-generated density-current flows of sand from the nearshore environment or the sediment flows may have been triggered by seismic activity (i.e. earthquakes).

Facies 3

Description: The facies consists of conglomerate beds and thin lenses with clast sizes reaching up to 15 cm in length. The matrix to clast ratio varies at different localities and the facies ranges from matrix- to clast-supported. Bed thickness varies and is generally less than 40 cm. Basal bed boundaries are often either erosional or diffuse. Clasts are predominantly volcanic in origin.

Interpretation: The thin pebbly lenses and lag deposits representative of Facies 3 reflect periods of winnowing, probably during storm events. Fluctuating energy levels within the system caused in situ disturbance above storm wave-base.

Facies 4

Description: This facies consists of poorly sorted fine- to coarse-grained sandstone that contains abundant volcaniclastic material, including euhedral plagioclase, subhedral augite and subangular to subrounded microlitic-rich volcanic fragments and clasts. Fossils are also present in this unit.

Interpretation: The subangular to subrounded nature of the lithic component of this facies suggests that the fragments have undergone minimal transport. The presence of unaltered augite suggests that deposition took place rapidly (as augite is prone to weathering). Deposition probably occurred rapidly from a series of subaqueous debris flows originating from shallow marine bars, deltas or the subaqueous extension of lahar flows off a volcanic edifice.

Facies 5

Description: In the Back Forest area on the southwestern flank of Mount Coolangatta, adjacent to the Shoalhaven River (elevation 30 m), a 2-4 cm thick fine-grained, hard, dark grey layer contains pumice and shard fragments. The unit is conformably interbedded with sandstone beds. The central part of this unit contains a very thin, single layer of coarse-grained lithic fragments up to 1 mm in size.

Interpretation: Pumice and shards suggest a volcanic source (explosive eruption). The presence of lithic fragments may indicate that there was a minor depositional hiatus during which time winnowing occurred. Alternatively, the layer may represent a pulse in the eruptive episode with the lithic fragments being autoclastic in origin. The eruptive centre may have been some distance from the site of deposition.

Facies 6

Description: Facies 6 consists of a 2 m thick, fossiliferous, pyroclastic tuff bed, containing abundant glass shards (reticulite; Fig. 2) and a pseudoeutaxitic texture. Feldspar phenocrysts and biotite are rare. *Warthia stricta* have been identified within the tuff, preserved in bedding-parallel alignment (A. Wright, pers. comm. 1999).

Interpretation: This facies is interpreted as a submarine pyroclastic flow originating from a proximal phreatomagmatic (hydrovolcanic) eruption into a shallow marine environment.

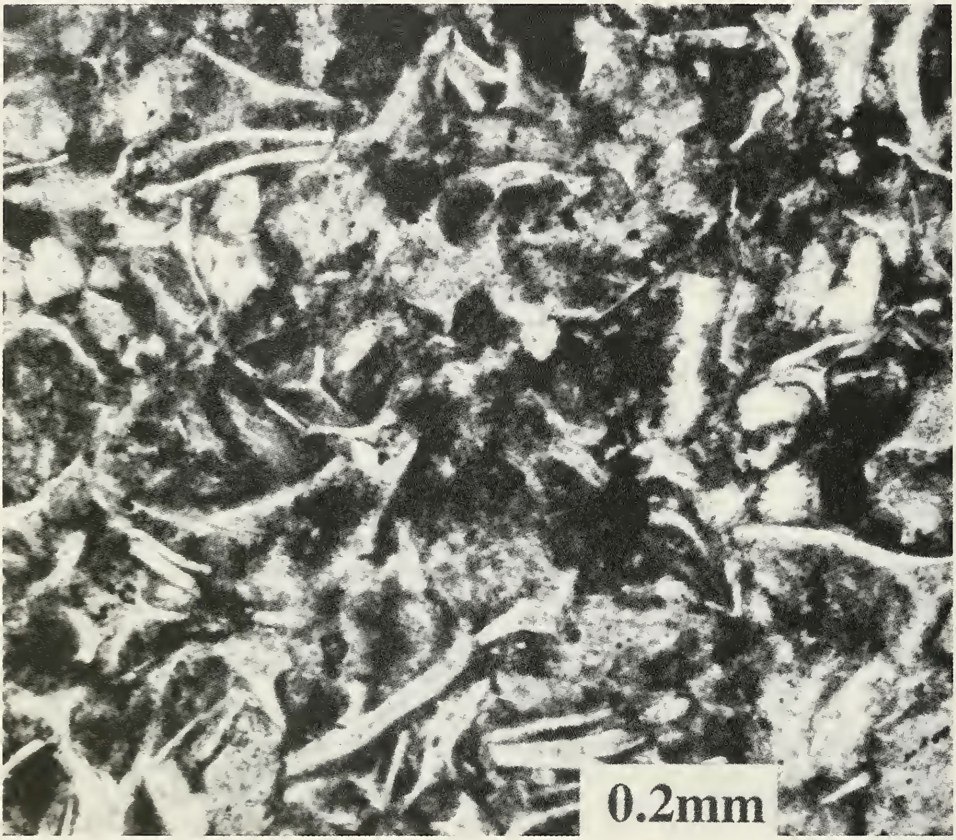

Figure 2. Chaotic glass shards in a cryptocrystalline vitreous matrix are a prominent feature in thin sections of the Koo-Lee Tuff Member. Plane polarised light.

SEDIMENTOLOGY

Berry Formation

Outcrops of this formation are indistinctly bedded (often as a result of biogenic homogenisation) to flat-bedded, mid- to dark-grey siltstone and very fine feldspathic litharenite (Facies 1). Thin, fine-grained, light-grey to light-brown (i.e. siderite stained) sandstone lenses gradationally and conformably interdigitate with the grey siltstone along the western side of Mount Coolangatta, which represents the upper part of the Berry Formation. The beds become thicker as they grade into the overlying Broughton Formation. Bases of the sandstone beds sometimes contain clasts of intermediate volcanic origin.

Primary sedimentary structures are difficult to ascertain, due to intense weathering and pervasive bioturbation. Lamination and micro-cross-bedding is evident in places in the small quarry east of Back Forest. Spheroidal or ‘onion-skin’ weathering, measuring up to 3 m in diameter, is a characteristic feature of the Berry Formation. Regional dip of the Berry Formation is about 2-3° to the northwest.

Westley Park Sandstone Member

Mount Coolangatta contains a complete succession of the Westley Park Sandstone Member, which can be seen to conformably overlie the Berry Formation in a small quarry at Back Forest. The Westley Park Sandstone Member consists of fine- to coarse-grained volcanic-derived litharenite throughout the entire succession, that changes colour from grey or greenish-grey at the base of the member to greenish-brown or pinkish-brown towards the top. Abundant body fossils are preserved at a few locations. Fossils include brachiopods (*Ingelerella* and a productid), bivalves (*Megadesmus*), digitate bryozoans and *Stenopora crinata*. Fossils preserved within one sandstone unit have been zeolitised, possibly caused by the effects of heat associated with volcanism (A. Wright, pers. comm. 1999). A thin tuff is interbedded within the lower part of the member east of Back Forest (56/288250E, 61401250N).

On Mount Coolangatta, porphyritic igneous units are intercalated, extrusively and contemporaneously, between sandstone beds of the Westley Park Sandstone Member between about 50 m and 230 m (Fig. 3). Two thin conglomerate beds (Facies 3) overlie the tuff bed of Facies 6 at about 120 m and contain abundant rounded volcanic clasts. A greenish-grey, coarse-grained volcaniclastic sandstone (Facies 4) occurs on the northeast flank of Mount Coolangatta. It contains abundant volcanic clasts up to 1 cm long, which themselves contain plagioclase microlites and augite (3 mm). Brachiopods were also obtained from this site. A breccia unit immediately below the first latite flow marks the top of the Westley Park Sandstone Member. It contains large white tabular plagioclase grains and abundant volcanic fragments.

The Westley Park Sandstone Member is approximately 190 m thick at Mount Coolangatta, exceeding the presumed 45 m suggested by Raam (1964, 1969) and Carr (1983).

Kiama Sandstone Member

For some distance above the Blow Hole flow the outcrop has been removed by weathering or concealed by vegetation and the lateral equivalents of the fluvial deposits and permafrost palaeosol reported from near Kiama by Retallack (1999) could not be observed. The latter palaeosol from near the base of the Kiama Sandstone Member contains abundant feldspar and pyroxene, and provides evidence of a humid frigid climate, with a boreal taiga type forest (Retallack 1999). Towards the summit of Mount Coolangatta (above 250 m) the Kiama Sandstone Member is at least 55 m thick, which is similar to the 53 m previously recorded at Jamberoo by Carr (1983). It is a characteristic pinkish brown to red (hematitic) silty marine sandstone showing some evidence of bioturbation. Brachiopods were identified within this unit, confirming its shallow marine origin.

VOLCANIC ASH AND TUFF DEPOSITS

Back Forest Tuff Bed

A thin tuffaceous ash deposit (Facies 5, averaging about 3 cm thick) was found in a disused roadside quarry near Back Forest Bridge (56/288250E, 61401250N), conformably interbedded within fine-grained sandstone near the base of the Broughton Formation. It has been named after the Back Forest area. Fragments of pumice with vesicles were identified in thin-section, as are the remains of glass shards contained in a pseudo-eutaxitic texture. Tiny fragments of latitic material and angular anhedral phenocrysts of plagioclase are also present. This deposit could not be traced laterally due to soil and vegetation cover. The tuff deposit is evidence of an explosive volcanic eruption, previously undetected in the southern Sydney Basin.

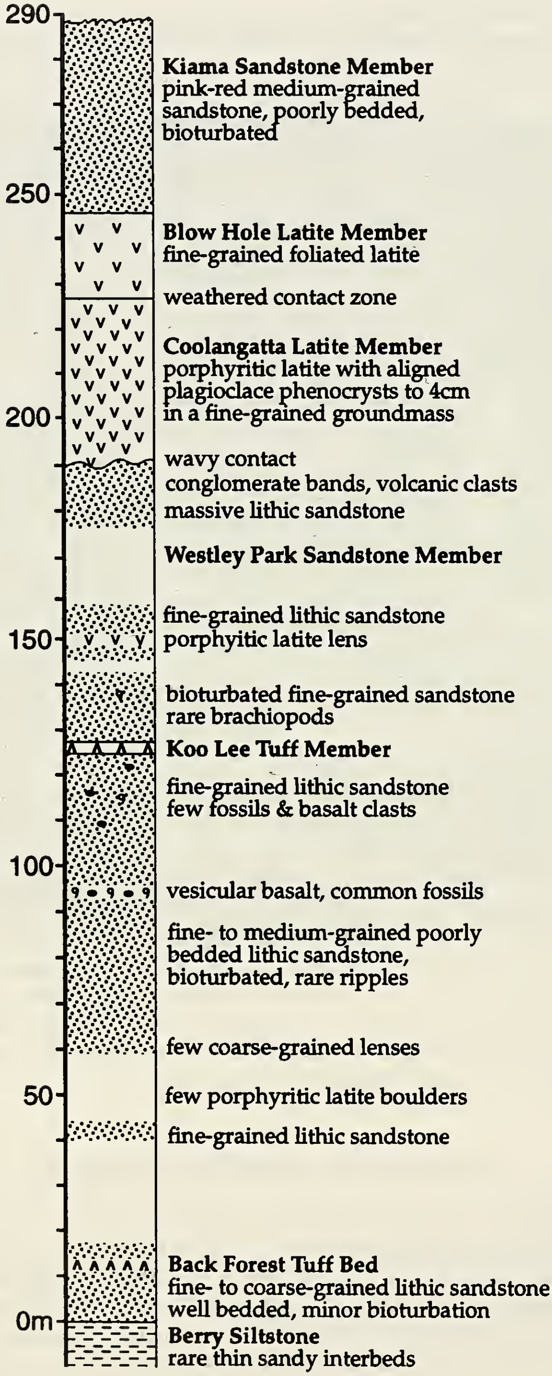

Figure 3. A detailed composite stratigraphic section through the Westley Park to Kiama Sandstone Members, lower Broughton Formation, on the eastern and southern flank of Mount Coolangatta.

Koo-Lee Tuff Member

A 2 m thick volcanic ash deposit (Facies 6) was found in a gully on the eastern side of Mount Coolangatta at an elevation of 120 m (56/291250E, 6141300N; type section) and also in gullies on the northern side of the mountain at approximately the same elevation. It is named after the Koo-Lee property on which it occurs. It is interpreted to occupy a position about 85 m above the base, and within the middle of the Westley Park Sandstone Member. This places the occurrence of this second volcanic ash event well before the previously documented initial flow of the Blow Hole Latite Member in the Gerringong Volcanics. The volcanic ash consists of reticulite, which contains chaotic glass shards mixed in a cryptocrystalline vitreous matrix with subordinate euhedral-subhedral opaque grains (magnetite), rare subhedral plagioclase with a perthitic texture, and small pleochroic biotite (Fig. 2). In places a eutaxitic texture is exhibited. Pumiceous material, a strong foliation parallel to bedding, and a sparse shelly fauna are also present. Fossils found within the tuff have been identified as the small marine gastropod *Warthia stricta* (Dana, 1849). This particular fossil was identified in the middle of the bed; however, other fossil fragments can be recognised throughout the tuff. These small gastropods are one of three Permian *Warthia* species found in the area, and they have also been identified in Permian strata in New Zealand (Waterhouse 1967). The presence of the fossils indicates that the tuff was emplaced in a shallow marine environment probably by a flow mechanism or as a primary air-fall ash.

LAVA FLOWS

In 1849 Dana suggested that the igneous rocks high on Mount Coolangatta were 'similar to the Kiama lavas', which crop out at sea level 12 km to the north. In 1915 Harper suggested the Bumbo flow occurred on the northern side of Mount Coolangatta while the southernmost outlier of the Blow Hole flow was at Toolijooa (KG965505) some 10 km northeast of Mount Coolangatta. In this study two lava flows are recognised above the Westley Park Sandstone Member on Mount Coolangatta, and thin flows are present at lower stratigraphic levels within the member.

Identification of a latite rock unit, 40 to 50 cm thick, was made low on Mount Coolangatta (elevation of approx 20 m) in a small gully covered with lantana (56/290675E 6141000N). This lower latite is conformable with the underlying and overlying sandstone strata. It is a dark greenish grey porphyritic latite with large preferentially eroded-out phenocrysts of plagioclase (labradorite) in a fine-grained groundmass. This same type of volcanic rock appeared again higher up on Mount Coolangatta, in a series of thin units interbedded with the sandstone (Fig. 3).

Coolangatta Latite Member

Immediately above the breccia at the top of the Westley Park Sandstone Member is a 30-40 m thick, dark grey, trachytic porphyritic latite extrusion, with plagioclase phenocrysts up to 4 cm in length (Fig. 4). This distinctive lower flow has been named the Coolangatta Latite Member since its major occurrence is on Mount Coolangatta.

The type section (56/291300E, 6141500N) is located on Mount Coolangatta between 204 m and 226 m elevation (Fig. 3). The Coolangatta Latite Member has a similar texture to the porphyritic stage of the Bumbo flow (P. Carr, pers. comm. 1999), being pilotaxitic. In hand specimen the rock is dark grey and fine-grained with plagioclase and a dark mineral (iron oxide or augite) present. It exhibits a porphyritic texture with large tabular plagioclase (labradorite) phenocrysts up to 4 cm long, that exhibit excellent twinning according to albite, pericline and albite-Carlsbad laws. Smaller, skeletal, twinned phenocrysts exhibit a glomeroporphyritic texture. Part of the member has a pilotaxitic (trachytic) texture with microlites exhibiting a lineation or pronounced flow texture. Plagioclase microlites make up the majority of the groundmass with subordinate pyroxene (augite) and opaque iron oxides (magnetite or/and hematite). Chlorite is present throughout the groundmass, as well as replacing mafic minerals (augite and possibly olivine). The fine-grained groundmass infiltrates cracks along twin planes in some of the large phenocrysts. This rock appears to be a latitic basalt.

The underlying breccia would have formed as a basal breccia layer when the lava flowed into the shallow marine environment represented by the upper part of the Westley Park Sandstone Member.

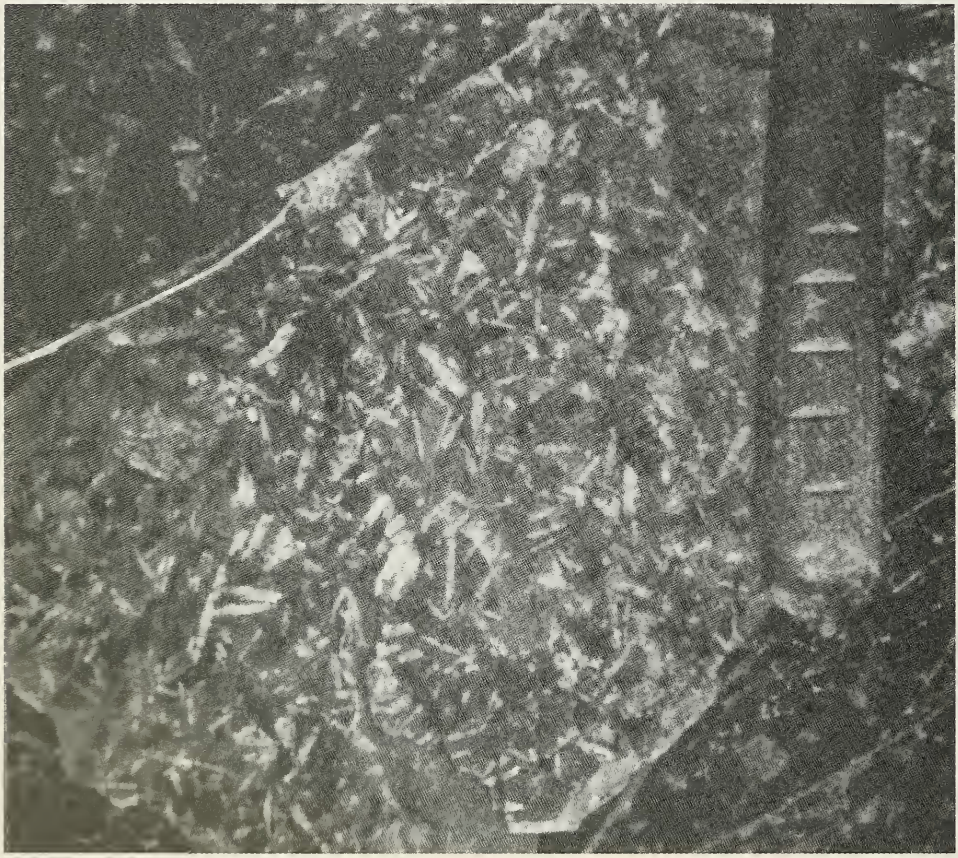

Figure 4. Coolangatta Latite Member showing large partly aligned plagioclase phenocrysts. The hammer handle is 35 mm wide.

Blow Hole Latite Member

The Blow Hole Latite Member consists of fine-grained slightly porphyritic latite occurring between 226 m and 242 m elevation near the top of Mount Coolangatta (Fig. 3). This latite unit exhibits a northwest-dipping flow foliation (Fig. 5) and an alignment of the phenocrysts present. However, it lacks the conspicuous large plagioclase phenocrysts found in the underlying flow. It is petrographically and geochemically the same as the remainder of the Blow Hole Latite Member (Carr 1984) and represents the southern extremity of this flow.

Figure 5. Typical finely crystalline Blow Hole Latite Member showing flow foliation (dipping to the north).

DISCUSSION

The Permian flows recorded from the Mount Coolangatta area have a porphyritic or glomeroporphyritic texture that is characteristic of coherent lavas, syn-volcanic intrusions and derived clasts. This criterion is critical when distinguishing coherent facies (lava flows) from pyroclastic, resedimented volcaniclastic and volcanogenic sedimentary deposits (Walker 1973). Volcanic rock units of similar age may have disparate petrographies due to different cooling histories of magma from the same magma chamber (i.e. successive eruptions with and without large phenocrysts). Plagioclase phenocrysts in the two flows commonly have a lighter, more sodic-rich rim than their core, creating a corona, whilst the rarer alkali feldspars often have a more calcium-rich rim. This chemical zoning may be due to albitisation. Sericitisation is indicated by sericite inclusions in plagioclase cores while chlorite and calcite can replace both groundmass and phenocrysts, including plagioclase, olivine and augite.

Cas and Wright (1987) and McPhie et al. (1993) suggested that flat and slightly curved, platy glass shards, similar to those in the Koo-Lee Tuff Member, are of a Surtseyan type. Such shards are produced when sea water acts to catalyse explosive fragmentation of an already vesiculated, basaltic magma that is in a state of incipient magmatic explosive disruption.

The abundant shards within the Koo-Lee Tuff Member suggests that a phreatomagmatic Vulcanian, Plinian or Surtseyan eruption to the south or southeast may have produced a surge that travelled across the water in a northward direction, depositing the Koo-Lee Tuff Member near the vent. Rapid deposition into a shallow marine environment is suggested by the homogenous vitric shard content (i.e very little sediment interbedded or mixed in), as well as the containment of *Warthia* (gastropod) and fossil debris within the middle part of the flow. The presence of *Warthia* suggests that the source location was proximal and the animals were buried either *in situ* or only transported a short distance. Ash fall deposits are often fossil-rich proximal to the source or wherever the tuff accumulation is thick (Lockley 1990). Some stratification in the tuff (i.e. variation in shard size or 'bedding') may reflect a progressive increase and/or fluctuation in eruptive vigour, or an interruption in the continuity of the eruption (Cas and Wright 1987; Scandone 1996), caused by temporary vent blockage, or rain showers during the eruption.

Volcanic Activity

The Back Forest Tuff Bed provides evidence for periodic volcanic activity during deposition of the lower Westley Park Sandstone Member. Incoming volcanic detritus led to the gradational change from the Berry Formation to the Westley Park Sandstone Member as volcaniclastic supply and proximity to volcano sources increased.

A probable Surtseyan pyroclastic eruption deposited a thick ash-flow, the Koo Lee Tuff Member, in proximal channels and distally as an ash-fall or a pyroclastic flow. Less violent eruptions followed, with extrusion of fluidal lava (latite) that flowed down the volcano flanks and into the sea formed the Coolangatta and Blow Hole Latite Members. Mafic lava can flow significant distances downslope, and underwater (Walker 1989, 1993) where the lava then accumulates due to reduction in slope at the foot of the volcano. The Westley Park Sandstone Member at Mount Coolangatta is interpreted as a sedimentary apron about a volcanic vent(s) on the northwest edge of the magmatic arc in the Currarong Orogen. It may represent a small or more distant component of a larger volcaniclastic apron surrounding a substantial volcano tentatively located 40 km to the southeast (i.e. in or southeast of Jervis Bay). The greater thickness (i.e. >150 m) of the Westley Park Sandstone Member on Mount Coolangatta than elsewhere (maximum 45 m) suggests that the local units represent a wedge of sediment deposited during periods of high energy (shallower water) as the apron extended northwards. Abundant volcaniclastic material would have been shed off the volcano into the basin as lahars, debris flows and turbidites.

The thick feldspar-phyric Coolangatta Latite Member flow was extruded onto unconsolidated wet sand and formed a breccia at the sediment-lava interface. The Blow Hole Latite Member was emplaced as a slightly younger flow before subsidence/ transgression occurred and the Kiama Sandstone Member was deposited. The relatively rapid rate of extrusion (i.e. 40 m of lava into a shallow marine environment) suggests a potential subaerial surface existed after the second flow. Evidence of subaerial weathering or sedimentation above the Blow Hole flow was not found (cf. Retallack 1999), however, benching near this contact on Mount Coolangatta indicates preferential erosion of the beds at this stratigraphic height. A transgression noted across the subaerial palaeosol on the Blow Hole flow near Kiama (Retallack 1999) suggests that the region had a low gradient, allowing reworking at the top of the flow that contributed to the deposition of the overlying marine Kiama Sandstone Member.

Palaeogeography

Sedimentation was drastically influenced by volcanoes to the south and southeast supplying voluminous volcanic material that overwhelmed the westerly-derived quartzose sediments from the Lachlan Fold Belt. The volcanoes may have aided mortality of fauna living in the shallow Permian seas at that time.

Glacio-eustatic cycles, mainly due to Milankovitch cyclicity, have affected Permian sedimentation in the southern Sydney Basin (e.g. Tye 1995; Barry 1997; Bann 1998). In the Mount Coolangatta area, the interpretation of sea level changes and flooding events on sedimentation is complicated by local volcanicity (i.e. regressions before eruptions due to magma chamber bulge and subsequent transgressions after eruption). The increased amount of sedimentation in volcanic settings due to rapid erosion of pyroclastic detritus (Orton 1995) may have choked the basin and enforced a regression. Vents and flows are also likely to reduce wave activity, alter palaeocurrent trends and deflect craton-derived sediment to other areas of the basin. Other tectonic influences varied the rate of subsidence, perhaps by foreland loading to the east under orogen stresses (i.e. subduction) or changes in basin hinge zone location.

CONCLUSIONS

Subaerial and subaqueous volcanic events and contemporaneous erosion of the volcanic edifices featured during the mid Permian in the southern Sydney Basin. The eastern Berry Formation contains abundant volcanic detritus, shed as turbidite flows off the flanks of a southern volcano near Jervis Bay. The stratigraphic succession graded upwards conformably from the Berry Formation into the Broughton Formation as the influx of volcaniclastic sand increased.

The Back Forest Tuff Bed within the lower Westley Park Sandstone Member contains latitic clasts, pumiceous material and glass shards, thus marking an explosive volcanic eruption. The Koo-Lee Tuff Member formed as a proximal, slightly fossiliferous pyroclastic vitric tuff that recorded a more violent Vulcanian, Plinian or Surtseyan phreatomagmatic eruption. *Warthia* fossils within the tuff bed reflect its submarine deposition. The Coolangatta Latite Member, a thick porphyritic mafic flow, records an early phase of lava activity within the Gerringong Volcanics that predates the Blow Hole flow.

Penecontemporaneous sedimentation included considerable volcaniclastic sediment derived from rapidly eroding volcanic vents and flanks. Abundant fine-grained volcanic material dominated over the westerly-derived quartzose sediments of the Lachlan Fold Belt. Depositional mechanisms were mostly pyroclastic surges and flows, storm-generated turbidity currents, and debris flows triggered by seismic activity (earthquakes).

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